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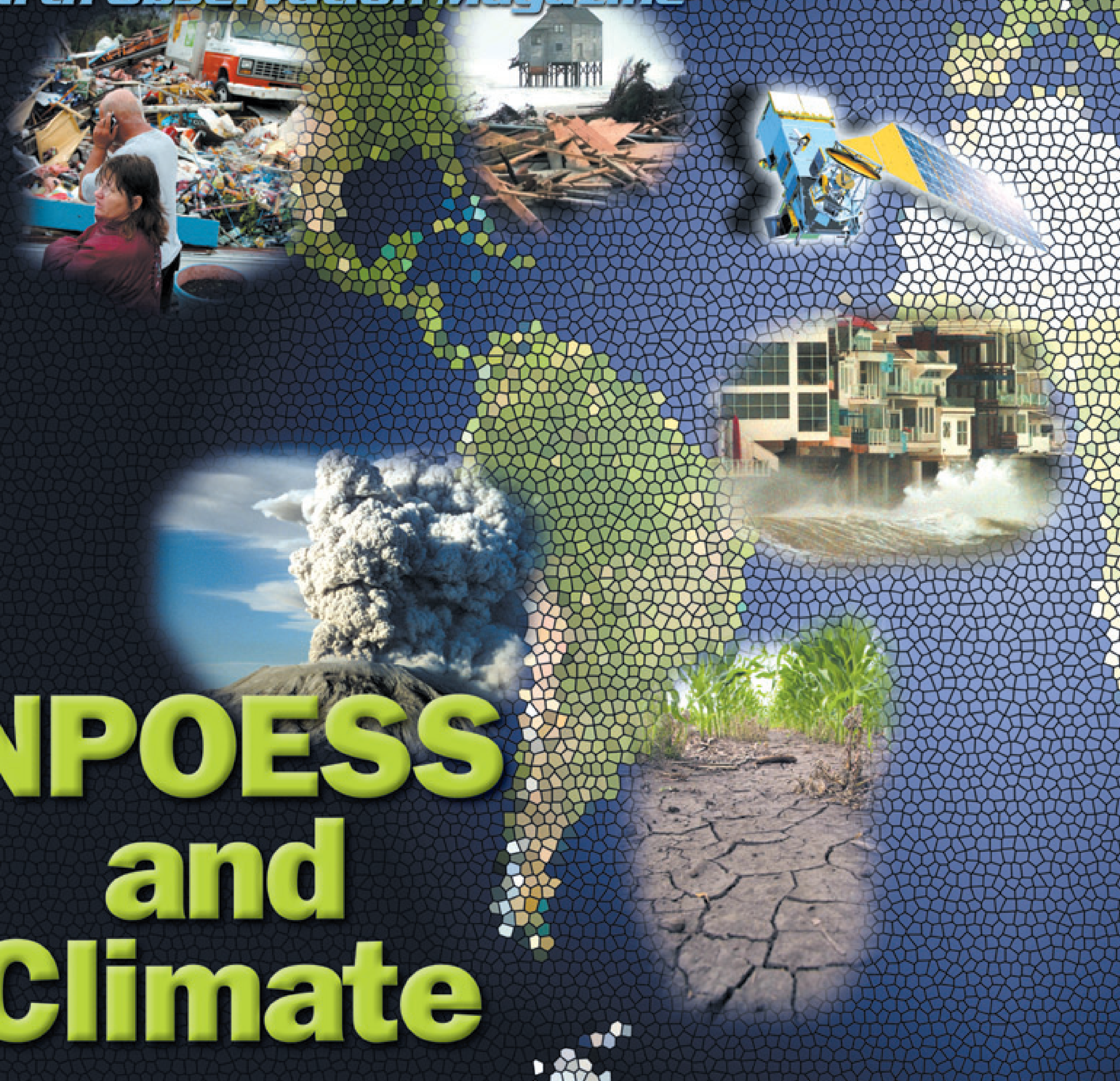

NPOESS and Climate

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NPOESS and Climate:

Part 1: The Challenges Ahead

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Dave Jones

This is the seventh in a series of articles on the National Polar-orbiting Operational Environmental Satellite System (NPOESS). One of the challenges for NPOESS is to collect critical information for operational use, especially for numerical weather prediction, while collecting high quality observations for longer-term monitoring and research on the Earth's changing climate. This special two-part article will focus first on identifying the differences between weather and climate and the importance of performing measurements that satisfy both. In this piece the differences between weather and climate, and the distinction between climate variations and climate change are explained. The second part in next month's issue will focus on describing how NPOESS will measure climate.

Figure 1 *The abnormal warming of the tropical Pacific Ocean (called El Niño) causes weather patterns to shift and severe weather to occur in more temperate areas. This image shows a strong Pacific storm affecting southern California. Wind-driven waves pound the pilings of oceanfront homes on the Pacific Coast Highway in Malibu, California on Friday, Dec. 5, 1997. Image courtesy: AP World Wide Photos*

Introduction: The Importance of Climate

The National Polar-orbiting Operational Environmental Satellite System (NPOESS), once operational, will meet the nation's needs for environmental measurements from satellites far into the future. Among these needs, none is more critical than climate; for climate strongly influences the nation's and the world's economy, sustainability, as well as the safety of life and property. Consider the year-to-year variations of climate and their impacts, from the effects of El Niño, droughts, and hurricanes to the long-term trends in climate, such as increasing surface temperatures, ozone depletion, and sea level rise. Climate is a global phenomenon; as such, having the ability to map the Earth globally on a daily basis is essential to observing and understanding our climate and its dynamic nature. Polar-orbiting satellites are the ideal platforms for climate monitoring and study. NPOESS presents a unique opportunity to make sustained long-term measurements and monitor the Earth's global climate.

Differentiating Weather, Climate, Climate Variation, and Climate Change

The distinction between the common terms "weather" and "climate" is not always clear. Weather represents the day-to-day changes of the atmosphere, and more broadly of the ocean and land. We experience it as wet or dry, warm or cold, windy or calm. Climate is the long-term average of weather conditions, where the average, or "normal," is usually computed from a recent 30-year period of weather observations. For example, the July "normal" climate of New York City is characterized by average rainfall of 4 inches, an average high temperature of 84° F, and an average low temperature of 68° F. In more technical terms, climate is a statistical description of weather, including its variability and extremes as well as averages.

Climate conditions are not steady; they vary or fluctuate. Scientists generally talk about two major kinds of climate variations—short-term and longer-term. Short-term climate fluctuations are departures from average weather conditions over a period of a month or more; they are generally referred to as climate variations. El Niños and droughts are examples of climate variations.

Variations in the weather and climate over the longer-term (decades, centuries, etc.) are generally referred to as climate changes; the ice ages are an example. Another distinction between weather and climate involves the controlling processes. In general, the weather is governed mainly by the atmosphere, its circulation and the processes within it, such as the formation of clouds and rain. Climate generally depends on additional atmospheric processes including chemical reactions that determine the concentrations of important constituents, such as ozone and methane, and processes that alter the radiation budget, such as the interactions between clouds and radiation. Climate also depends on the important interactions between the atmosphere and the other components of the Earth's climate system—the oceans, the land, the cryosphere (the snow and ice cover of the Earth), the biosphere—and the sun. The Sun's radiation striking the Earth is the driving force for climate. Its diurnal (daily), latitudinal, and annual variations cause the day to night, equator to pole, and summer to winter climate extremes.

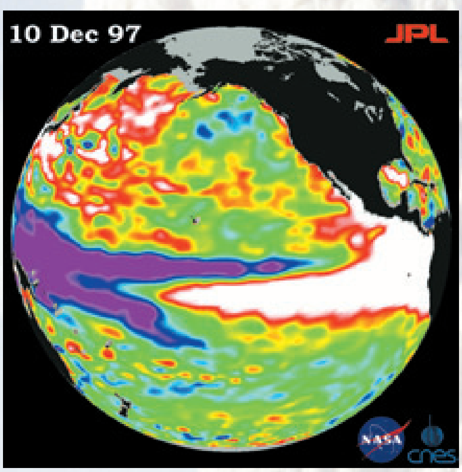

Figure 2 This image of the Pacific Ocean shows the El Niño that led to strong Pacific storms damaging coastal locations along California as shown in Figure 1. The image was produced using sea surface height measurements taken by the U.S.-French TOPEX/Poseidon satellite. The image shows sea surface height relative to normal ocean conditions on Dec. 10, 1997. Sea surface height is an indicator of the heat content of the ocean. The volume and area of the warm water pool related to El Niño increased after reaching a temporary low around December 1.

The oceans play an important role in climate, acting as a reservoir for heat. Surface and subsurface ocean currents transfer large amounts of heat around the globe, modulating climate and climate change. Heat, momentum, and water are constantly being exchanged between the ocean and the atmosphere. Productivity within the ocean, a function of the immense populations of small drifting plants, also acts to absorb or release carbon, thus impacting its global cycle on the planet.

The land surface, including its vegetation and seasonal snow cover, also influences climate. The land affects the flow of air over it, the absorption of solar energy, and the water and carbon cycles. In addition, explosive volcanic eruptions may release large quantities of dust and chemicals, such as sulfur dioxide that is converted to sulfate aerosols in the stratosphere; these sulfate aerosols reflect solar radiation causing significant global cooling at the Earth's surface and lower atmosphere for a year or more. Cryospheric snow and ice cover, including sea-ice in the Arctic and southern oceans and the land-based ice-sheets of Greenland and Antarctica are excellent reflectors of sunlight. Any process that significantly alters snow and ice-cover can affect polar climates as well as that of the entire planet.

While natural forces are the major determinant of climate, the activities of humankind may be altering its path. Burning of fossil fuels releases carbon dioxide and smoke aerosols into the atmosphere, and these pollutants perturb the Earth's radiation balance, which leads to climate change. Further research is ongoing to measure and calculate the amount of influence humankind is having on climate change.

The potential socio-economic effects of long-term climate change can only be roughly estimated. However, studies suggest that global climate change will have profound impacts on society, as shown in **Figure 4**.

Measuring Climate

Both weather and climate measurements must be made on a global scale. For climatic variables with large diurnal variations (*e.g.,* solar radiation, temperature, clouds, and precipitation), it is also desirable to sample the complete daily cycle. Because climate is an average of weather conditions over time, observations of all the weather elements, such as temperature, humidity, wind, rain, etc., are needed.

Additional observations of the sun and other components within the climate system are required. Long-term variations in solar radiation do occur and can affect the climate; satellites are excellent platforms for observing such variations because they fly above the perturbing effects of the atmosphere. The radiation budget represents the balance between incoming energy from the Sun and outgoing thermal (longwave) and reflected (shortwave) energy from the Earth. Changes in the radiative energy balance of the Earth-Atmosphere system (caused, for example, by increasing amounts of carbon dioxide and aerosols) can cause long-term changes in climate. Satellites orbiting above the atmosphere are ideal for measuring the radiative energy streams into and out of the Earth-Atmosphere system.

Measurements of additional atmospheric variables of critical importance

Figure 3 *Volcanic dust can block out incoming solar radiation and actually decrease the tropospheric temperature around the world. These alterations in temperature can affect short and long-term climate conditions. Shown here, Mt. St. Helens erupts on July 22, 1980 spewing millions of tons of ash and soot into the atmosphere.*

to climate, including cloud properties, ozone, aerosols, and greenhouse gases, such as carbon dioxide are needed. Aerosols are defined as suspensions of liquid droplets or solid particles in the atmosphere, *e.g.,* smoke, dust, sand, volcanic ash, sea spray, polar stratospheric clouds, and smog. Ocean variables that are important for climate include sea surface temperature, sea level, salinity, and ocean color (for information on ocean productivity and the oceanic component of the Earth's carbon cycle). Even very small annual variations in sea level can have devastating consequences for small islands and low-lying coastal areas. Needed land observations include vegetation (for the terrestrial component of the Earth's carbon cycle), soil temperature, and soil moisture. Important cryospheric observations include snow cover and depth, sea-ice cover and thickness, and ice-sheet cover and thickness.

Challenges in Climate Observing from Space

As detailed in previous articles in this series, a sun-synchronous, polar-orbiting satellite can observe each location on the Earth every 12 hours. With the NPOESS constellation of three orbiting platforms, each spot on Earth will be observed approximately every four hours near the Equator and more frequently at higher latitudes. Thus, NPOESS will provide complete global coverage daily and resolve the diurnal cycle for some observations. Geostationary satellites, with

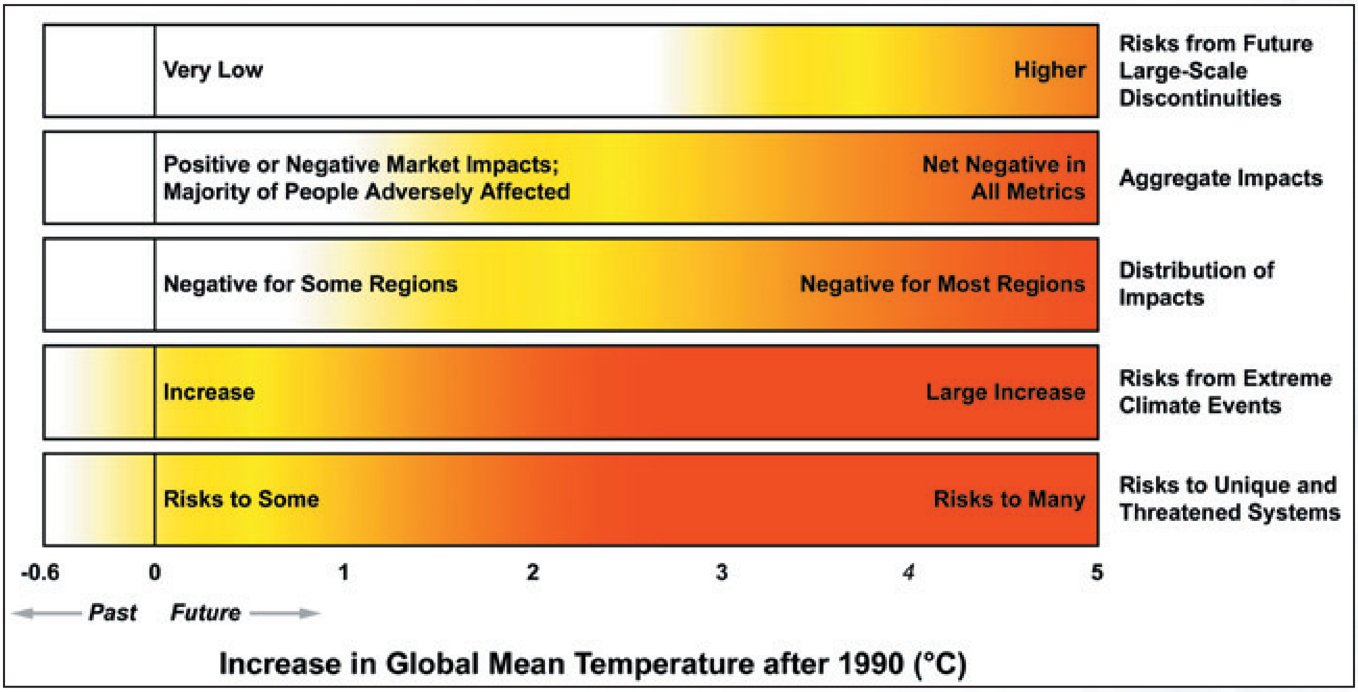

Figure 4 *Impacts of, or risks from, climate change, by reason for concern. Each row corresponds to a reason for concern, and shades correspond to severity of impact or risk. White means no or virtually neutral impact or risk, yellow means somewhat negative impacts or low risks, and red means more negative impacts or higher risks. Impacts are plotted against increases in global mean temperature after 1990. Global-averaged temperatures in the 20th century increased by 0.6C and led to some impacts. This figure addresses only how impacts or risks change as thresholds of increase in global mean temperature are crossed, not how impacts or risks change at different rates of change in climate. These temperatures should be taken as approximate indications of impacts, not as absolute thresholds. (IPCC, 2001: Climate Change 2001: Impacts, Adaptation and Vulnerability)*

***Figure 5** April 3, 2004: Ankit Stephan stands at the edge of a lagoon whose encroaching waves are toppling shoreline coconut trees. Small island states and low-lying coastal regions are at risk to increasing sea level which can compound the eroding effects of even mild storms that are eating away beaches across the tropics. Information gained from NPOESS and from other future ocean surface topography satellite missions will ensure the continuity needed to monitor and forecast changes in sea level worldwide.*

their continuous observations of the same areas of the Earth, can help to fill in the diurnal cycle of some of the climate variables.

There are several important distinctions between observations needed to predict the weather and measurements required to monitor and understand the Earth's climate and climate change. For one, predicting weather requires a good set of observations at a single time; monitoring climate fluctuations calls for a longer time series of observations.

The anticipated signals associated with global climate change (*e.g.*, temperature increase or decrease of tenths of a degree centigrade per decade; global mean sea level rise of 2-3 centimeters per decade) represent difficult measurement challenges. Observations must be able to resolve very small variations and they must be made continuously over a sufficiently long time period. The term Climate Data Record (CDR) has been introduced to denote a time series that has sufficient stability, length, and continuity to define climate variations and change. Observing long-term climate change also requires instruments whose measurement characteristics do not change appreciably with time.

The generation of satellite-based CDRs requires many inter-related activities and steps. These include: inter-calibration of identical instruments carried on different NPOESS spacecraft as well as intercomparison with similar instruments carried on other spacecraft (*e.g.,* National Aeronautics and Space Administration [NASA] research satellites); development of processing algorithms; detection and elimination of systematic errors in data; generation of stable time series; validation of data products; reprocessing of data as improvements are made to processing algorithms; and quality control and analysis of data.

In addition, satellite systems require that certain factors be minimized or accounted for in the creation of stable CDRs. These include the biases inherent in the observing instruments; changes in instrumentation; satellite orbital drift; system calibration; sensor degradation; and system malfunctions.

Measuring the required climate variables and doing so with the accuracy and long-term stability needed to detect climate variations and change are major challenges for NPOESS. Part 2 of this article will detail how NPOESS expects to meet these observational challenges.

The contents of this paper are solely the opinions of the authors and do not constitute a statement of policy, decision, or position on behalf of the NOAA, NASA, or the U.S. Government.

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NPOESS and Climate

Part 2: Making the Measurements

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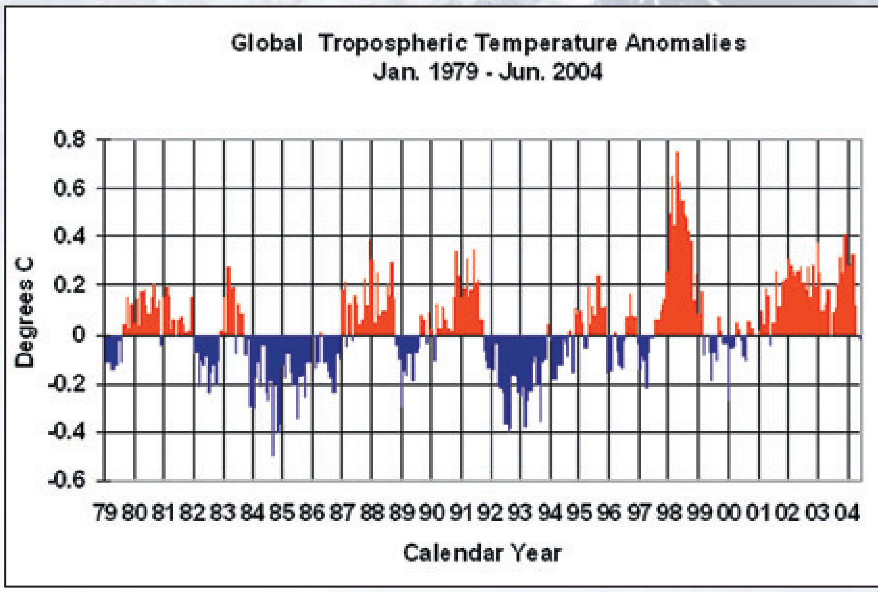
Meteorologist Andrew Shashy works on an extended weather forecast as a monitor above him displays a Global Forecast System model prediction for Hurricane Frances and other weather patterns on Saturday, September 4, 2004, at the National Weather Service facility at Jacksonville International Airport in Jacksonville, Florida.
Image courtesy: AP World Wide Photos

This is the second part of a two-part article on just how the National Polar-orbiting Operational Environmental Satellite System (NPOESS) will measure the Earth's climate. Multiple sensors on NPOESS will make the observations, which must be collected, processed, quality controlled, and used as input, into decision support systems, such as numerical weather prediction models and climate change assessments. Unfortunately, no single "environmental sensor" exists that can provide scientists with a critical single measurement of the Earth's long-term climate system. One of the challenges for NPOESS is to collect critical information for operational use while simultaneously collecting high quality observations for longer-term monitoring and research on the Earth's changing climate.

The NPOESS Climate Mission

Today, operational earth-observing satellites provide more than 99% of the observations used in computer-driven weather forecasts—the backbone of all weather predictions. The bulk of these observations come from polar-orbiting satellites. These systems also provide useful climate information, in particular on climate variations. Climate is of primary importance in the NPOESS program as shown by its plan to minimize measurement bias errors and to maintain the long-term stability of instruments, a critical requirement for constructing reliable long-term climate records. The design lifetimes of the NPOESS satellites are about twice those of the current operational satellites, 5-6 years vs. 2-3 years. This is a significant advance for climate applications because it will reduce the uncertainty that results when records from successive satellite instruments are compiled to create a long-term climate data record. The NPOESS program will try to assure the continuity of observations from instruments on the National Oceanic and Atmospheric Administration's (NOAA) Polar-orbiting Operational Environmental Satellites (POES), the Department of Defense's (DoD) Defense Meteorological Satellite Program (DMSP) spacecraft, and the National Aeronautics and Space Administration's (NASA) Earth Observing System (EOS) satellites that are essential for the construction of long-term climate data records.

In comparison to their current operational counterparts, the NPOESS instruments will also have much better spatial and temporal resolution, as well as more spectral channels of observation. NPOESS will provide new observations, for example, the composition and size of atmospheric aerosol particles. The effect of these particles on climate forcing—through their influence on the Earth's radiation budget and on cloud and precipitation formation—is a major unknown. NPOESS will measure climate variables not currently observed by the operational satellites, providing sustained measurements of solar radiation, sea level, and the Earth's radiation budget. Such measurements have been made in a research mode with no commitment to a long-term continuity of observations.



Global atmospheric (lower troposphere) temperature trends from the NOAA POES Microwave Sounding Instrument. Red is an increase in the temperature from the average and blue is a decrease in temperature. The temperature in this region is strongly influenced by oceanic activity, particularly the "El Niño" and "La Niña" phenomena.
Image courtesy: University of Alabama, Huntsville

NPOESS Instruments and the Climate Mission

In this section, we review the planned NPOESS instruments, describe their contributions to the climate mission, and present some examples of the climate applications of current satellite instrumentation.

The Advanced Technology Microwave Sounder (ATMS)

The ATMS will continue and improve upon the measurements of NOAA's Microwave Sounding Unit (MSU) and Advanced Microwave Sounding Unit (AMSU) instruments. The MSU and AMSU have provided critical data on long-term changes in atmospheric temperatures. However, the trends from such observations are uncertain due to calibration problems and the drifting orbits of the NOAA POES spacecraft that cause the daily observing time to drift over the satellite's lifetime. As a result, different investigators have applied various schemes to account for these effects and have come up with differing temperature trends. Higher values agree with the average, *in situ* global warming rate at the Earth's surface and lower values suggest that the atmosphere is warming only at a negligible rate. NPOESS satellites will maintain constant equatorial crossing times and altitude throughout the mission lifetime. This capability to make measurements at "precisely" the same time each day is important to maintain consistency in the long-term data records required for climate change analysis and assessment.

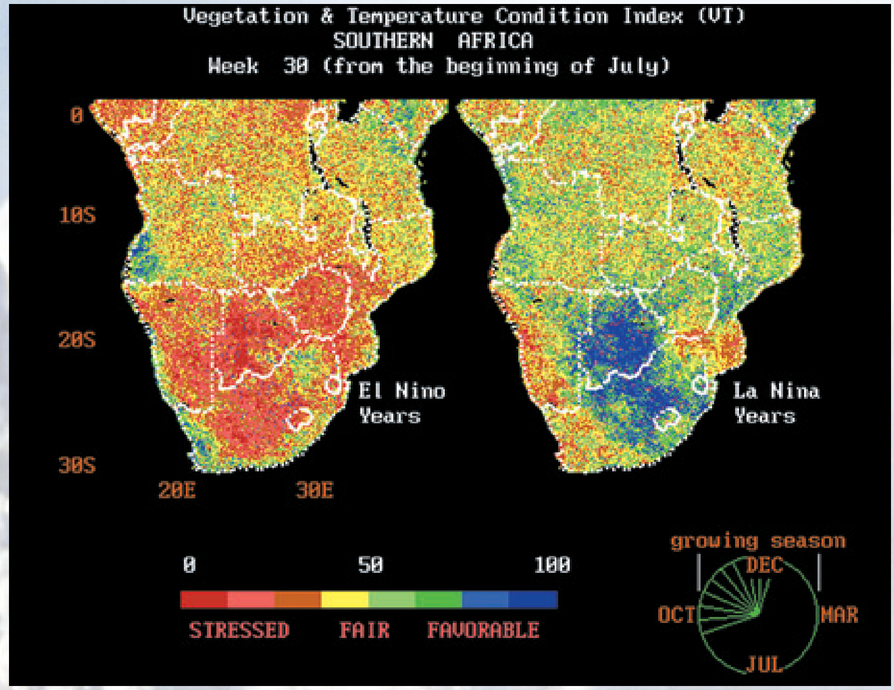
The Cross-track Infrared Sounder (CrIS)

The CrIS will provide substantially improved measurements of the temperature and moisture profiles in the atmosphere. The current High-resolution Infrared Radiation Sounder (HIRS) instrument on POES contains 20 infrared (IR) channels of information. CrIS will have more than one thousand spectral channels in the infrared. The large number of channels coupled with more refined spectral resolution will enable CrIS to measure temperature and moisture at better vertical resolution and with greater precision. CrIS will also have improved horizontal spatial resolution and provide unique information on clouds and greenhouse gases. CrIS will provide continuity with the NASA EOS Atmospheric Infrared Sounder (AIRS) instrument that is currently flying on the Aqua satellite.

The Ozone Mapping and Profiler Suite (OMPS)

The OMPS will measure the total amount and vertical profile of atmospheric ozone and continue the daily global data produced by the current ozone monitoring systems: the Solar Backscatter Ultraviolet spectral radiometer (SBUV)/2 and Total Ozone Mapping Spectrometer (TOMS), but with higher fidelity. The OMPS is comprised of two sensors—a nadir-viewing sensor and a limb-viewing sensor. Both sensors will maintain long-term data product stability through periodic solar irradiance measurements.

The SBUV/2 heritage instrument has been used to monitor the Antarctic ozone hole and the destruction of the



Typical patterns of vegetation conditions for El Niño and La Niña years in southern Africa from NOAA POES AVHRR observations. Red color represents stressed vegetation conditions (drought); blue portrays unstressed vegetation state. VIIRS, with its on-board visible calibration and finer scale horizontal detail, will permit more reliable quantification of El Niño effects on vegetation. Image courtesy: NOAA NESDIS

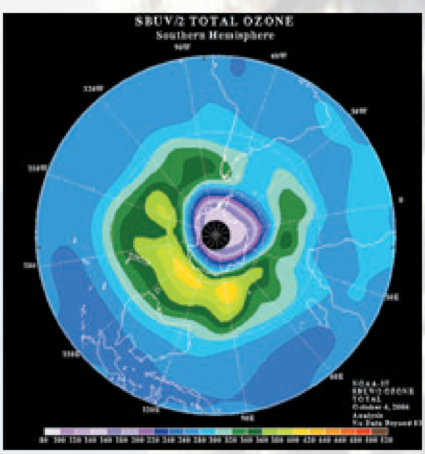
ozone layer by industrial chlorofluorocarbons (CFCs). The NPOESS OMPS will monitor the recovery of the ozone layer with the phase out of CFCs and will do so with much improved measurements of ozone profiles in the stratosphere, where these changes are occurring.

The Visible/Infrared Imager Radiometer Suite (VIIRS)

The VIIRS will combine the radiometric accuracy of the Advanced Very High Resolution Radiometer (AVHRR) currently flown on the NOAA POES spacecraft with the high (0.65 kilometer) spatial resolution of the Operational Linescan System (OLS) flown on DMSP. The VIIRS will have more than 20 spectral channels in the visible, near-infrared and infrared, and provide information on sea surface temperature, vegetation, clouds, aerosols, snow and ice cover, and, for the first time, operational measurements of ocean color. VIIRS will have on-board calibration of its visible channels, remedying a significant impediment to climate monitoring applications from its operational heritage instruments.

The Total Solar Irradiance Sensor (TSIS)

The TSIS will measure the total radiation from the Sun as well the spectral distribution of solar radiation from 0.2-2 micron. Instruments currently flying on NASA's Solar Radiation and Climate Experiment (SORCE) mission will provide historic data. The TSIS will supply measurements of total solar radiation with an absolute accuracy of 0.01%, and a long-term relative accuracy of 0.001% per year.



The purple areas over Antarctica in this color-coded image of Southern Hemisphere ozone amounts from SBUV/2 observations are the 2004 ozone hole. Highest ozone values are blue, lowest, pink. The black disk in the center is the region of winter darkness where the instrument, which measures solar ultraviolet radiation scattered back by the atmosphere, cannot obtain measurements. Image courtesy: NOAA Climate Prediction Center

The Earth Radiation Budget Sensor (ERBS)

The ERBS will be similar to its heritage instruments flown on NASA's Earth Radiation Budget Experiment (ERBE) and Clouds and the Earth's Radiant Energy System (CERES) missions. These sensors measure the total amount of solar radiation reflected and the total amount of long-wave radiation emitted to space by the Earth's surface, clouds, and atmosphere. NPOESS will ensure the sustained, continuous measurements of the Earth's radiation budget that are needed for climate studies.

The Conical-scanning Microwave Imager/Sounder (CMIS)

The CMIS will collect global microwave radiometry and sounding data to produce microwave imagery and other atmospheric and oceanic data. CMIS will observe at 77 microwave channels, covering the spectral range from 6.6 to 183 GHz, with a horizontal resolution from 15-50 km, depending on the data product. Data products will include atmospheric temperature and moisture profiles, precipitation rates, snow and ice cover, cloud water and ice content, sea surface winds (speed and direction), sea surface temperature, and soil moisture. Of particular importance to climate applications are the low frequency channels on CMIS at 6.6 and 10 GHz, which will enable the first operational measurements of soil moisture, a key variable about which very little is known for both interannual climate variations and long-term climate change. The low frequency channels will allow "all weather" determination of sea surface temperature (SST), another key climate variable. The capability of obtaining SST observations even under cloudy conditions overcomes a drawback of the traditional IR observations of SST.

The Aerosol Polarimetry Sensor (APS)

The primary mission of the APS is to provide high quality radiometric data as a function of polarization in the visible through short-wave infrared spectral regions in support of climate studies. APS will measure radiance in orthogonal polarizations at multiple wavelengths and viewing angles to produce data on aerosol total amount, particle size, shape, scattering albedo, and refractive index. These measurements will enable scientists to determine the absorption and scattering characteristics of aerosols that control the effects of aerosols on climate. These effects are of two types: the direct effect—the influence of the particles on the reflection or solar radiation or absorption of Earth's long wave radiation—and the indirect effect—the influence of aerosols on cloud and precipitation formation.

Summary

NPOESS will significantly advance the nation's ability to monitor global climate variations and change. NPOESS is the first operational environmental satellite system that has been designed from the outset with climate as one of its missions. Realizing the full benefits of NPOESS for climate will not be easy. Monitoring and early detection of climate change requires highly stable instruments, a major challenge for NPOESS. This challenge is also an opportunity—an opportunity to provide policy makers with the information they need to make informed decisions about adaptation, mitigation, and prevention strategies for climate variations, change, and their impacts.

The ground is cracked from lack of rain between rows of corn in some fields on Jim Frauenberg's farm near La Moure, North Dakota in July 2002. La Moure had little rain during this growing season but enough to sustain plants. Frauenberg, whose corn yields have won awards, employs a no-till method to preserve soil moisture. NPOESS will be able to collect the first known operational measurements of soil moisture. Image courtesy: AP World Wide Photos

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